

# Distribution of very young stellar clusters in grand-design spirals

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## Abstract

Many grand-design spiral galaxies display strings of knots along their arms on K-band images. Near-infrared (NIR) spectra and broad band colours of such knots have identified them as very young, massive stellar complexes. The low absorption in the NIR makes it possible to derive complete statistics of such complexes and thereby estimate the associated star formation rate. We have obtained deep NIR maps of 8 grand-design spirals using HAWK-I/VLT and identified massive complexes with ages  $<10$  Myr using NIR colour-colour diagrams.

The youngest, most massive complexes are well aligned and concentrated in the arms regions of the grand-design galaxies with strong spiral perturbations. Their absolute magnitudes have a bright tail reaching almost  $M_K = -16^m$ . Both fraction of young to old sources and the ratio of diffuse and more compact objects suggest a dependency on the strength of the spiral pattern in the host galaxy.

## Introduction

Blue, young objects (such as HII regions and OB associations) are often concentrated in the arms of grand-design spiral galaxies, however, strong and very varying attenuation by dust in the arm regions makes it difficult to study complete samples of such very young, stellar cluster in visual bands. It was noticed by Grosbøl & Patsis (1998, A&A 336, 840) that several spiral galaxies had bright knots along their spiral arms on K-band images. Grosbøl et al. (2006, A&A 453, L25) identified such knots in NGC 2997 with very young stellar cluster (ages  $<10$  Myr) using K-band spectra obtained at ISAAC/VLT while Grosbøl & Dottori (2008, A&A 490, 87) discussed their statistics in a sample of 46 spiral galaxies.

The current paper presents preliminary results on the distributions of young stellar complexes in 8 grand-design spirals for which we obtained deep NIR surface photometry from HAWK-I.

Table 1: General properties for the 8 galaxies such as Hubble type and distance derived from galactocentric GSR velocities and  $H=73\text{km/s/Mpc}$ . Absolute total B magnitude and linear scale were computed from the distances listed. The level for  $S/N=5$  per pixel and the FWHM seeing for the stacked K-band images are also given.

Galaxy	Type	Distance Mpc	MB mag	Scale pc/arcsec	S/N=5 (K) mag	Seeing (K) arcsec
NGC 157	Sc(s)II	23.5	-20.6	114	23.9	0.4
NGC 1232	Sc(rs)I	21.0	-21.4	102	24.0	0.5
NGC 1300	SBb(s)I.2	20.6	-21.1	100	23.8	0.6
NGC 1365	SBb(s)I	20.7	-22.1	101	23.8	0.4
NGC 2997	Sc(s)I.3	11.9	-20.8	58	23.6	0.4
NGC 4321	Sc(s)I	20.9	-21.8	101	23.7	0.6
NGC 5247	Sc(s)II	17.2	-20.5	83	23.7	0.4
NGC 7424	Sc(s)II.3	12.7	-19.9	62	24.6	0.4

## Data and Reductions

Deep NIR exposures of 8 grand-design, spiral galaxies were obtained in the JHK-bands with HAWK-I/VLT which has a  $7'$  field and  $0.11''$  pixels. The observations were done in service mode, late 2008, using standard jitter techniques with interleaved offsets to 'empty' sky fields. The basic reductions followed the procedure outlined in Grosbøl et al. (2004, A&A 423, 849). The galaxies are listed in Table 1 which includes limiting magnitudes and seeing for the final, stacked K-band images (see Fig.1). The photometric zero-points were derived directly from 2MASS stars in the fields. The seeing of  $\sim 0.5''$  allows objects with a linear size of more than  $50\text{pc}$  to be resolved.

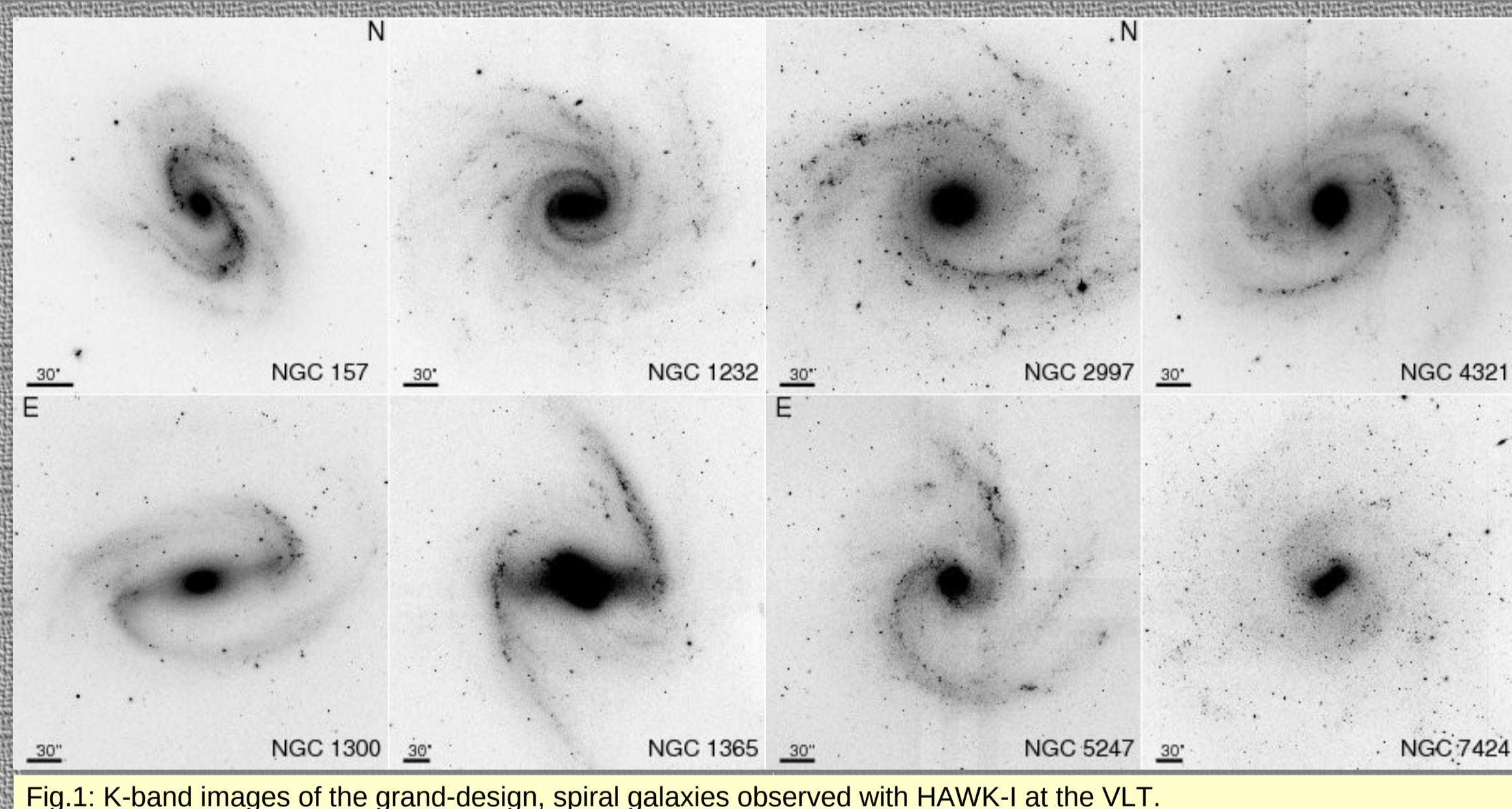


Fig.1: K-band images of the grand-design, spiral galaxies observed with HAWK-I at the VLT.

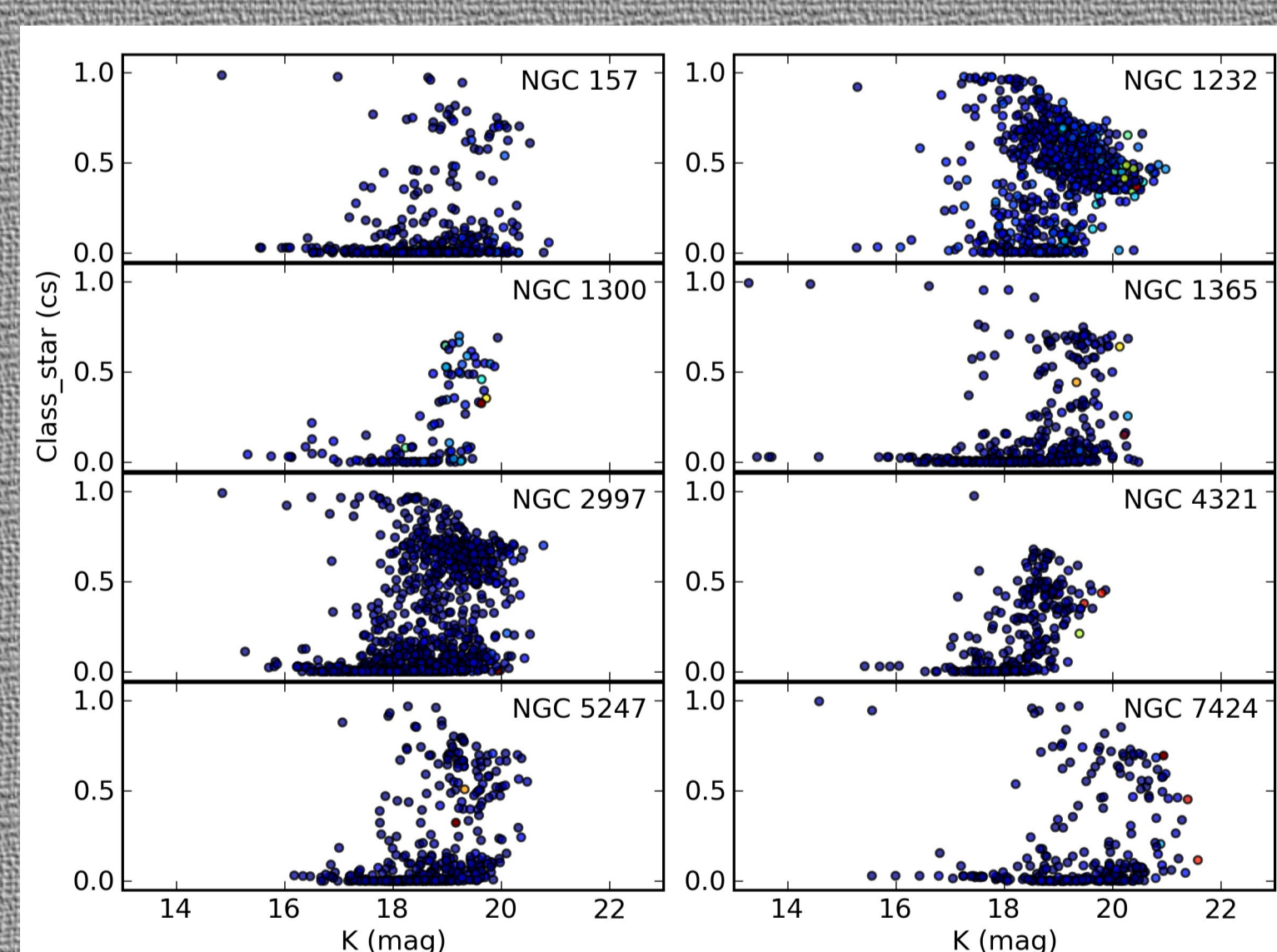


Fig.2: Sextractor class\_star (cs) classifier for 'young' objects (i.e.  $0.1^m < Q$ ) found in the disks of the 8 spirals as function of their K-band apparent magnitude. Stellar sources have  $cs \sim 1$  whereas diffuse, extended ones have  $\sim 0$ .

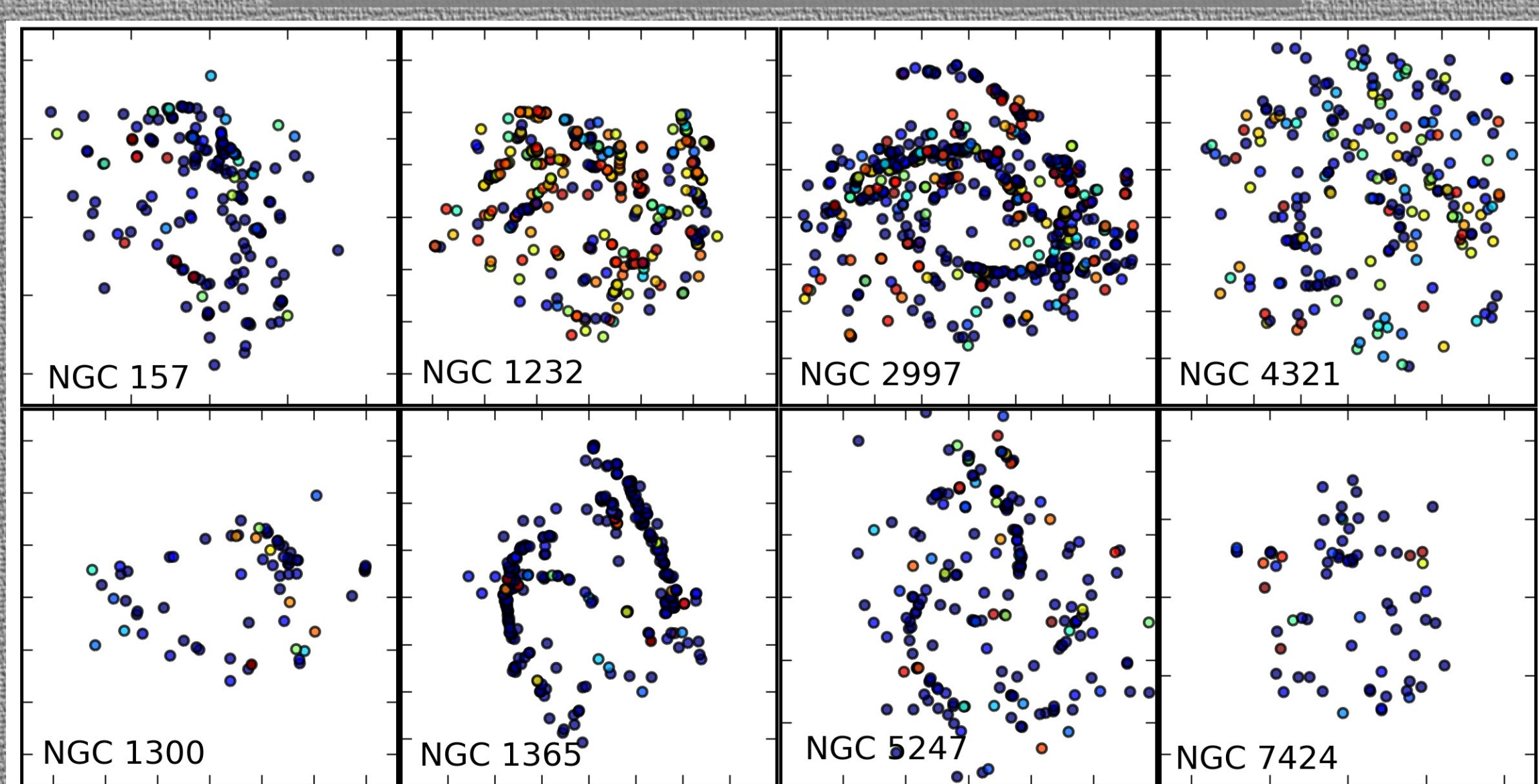


Fig.3: Location of young sources ( $0.1^m < Q$ ) in the disks of the spirals.

## Discussion and Conclusions

Deep JHK maps of 8 grand-design spirals were obtained and all extended sources in their disks with  $K < 22^m$  identified. The 5 spirals with stronger perturbations have a higher relative fraction of diffuse, bright sources compared to compact, fainter ones than the galaxies with weaker arms. The strong spirals also display a higher concentration of diffuse, young sources in their arm regions. The (H-K)-(J-H) colour distributions are consistent with the extended sources being stellar complexes with several magnitudes of visual extinction.

The absolute magnitude distribution of young sources have a bright tail which reaches almost  $M_K = -16^m$  while the faint end indicates a sharper decline. Both the relative fraction of young to older complexes and the ratio between diffuse and compact sources suggest a dependency on the strength of the spiral perturbation of the host galaxy, however other factors such as the amount of gas and dust may also play a significant part.

The alignment of bright, star forming complexes in the arm regions of grand-design galaxies with strong spiral perturbations suggests that the presents of such perturbations affects the star formation (e.g. through large-scale shocks) by enabling the formation of larger, more massive complexes. The formation of smaller clusters is seen over the entire disk.

## Detection and Distribution of Sources

All sources on the K-band images were identified using Sextractor (Bertin & Arnouts 1996, A&AS 117, 393) with a threshold of 3 and a background grid of 50 to better follow the surface brightness variations in the disks of the galaxies. With these positions, aperture photometry of the sources on the JHK frames were measured using a  $2''$  aperture and local background. Individual errors were estimated including scatter in the background measure. Only sources within the galactic disks (i.e. those with a background significantly higher than the sky) were considered, significantly reducing the 'pollution' of the sample by background galaxies.

The Sextractor class\_star classifier (cs) for the objects with  $0.1^m < Q$  is shown in Fig. 2 as function of their apparent K magnitude where the colour index  $Q = (H-K) - 0.59 \times (J-H)$  is 'reddening corrected'. Standard StarBurst99 models (Leitherer et al. 1999 ApJS 123, 3; SB99) of stellar cluster suggests that this index is a good age indicator for  $0.1^m < Q$  which corresponds ages  $< 10$  Myr. The fraction of compact (high cs) to diffuse (low cs) sources vary significantly from galaxy to galaxy and may suggest that spirals with stronger arms have relative more diffuse sources. A tail of very bright, diffuse objects are seen in most of the galaxies.

The spatial distributions of the young, extended sources are displayed in Fig. 3. They are concentration to the arms regions in the galaxies with strong spiral perturbations (NGC 157, NGC 1365, NGC 2997, NGC 4321, and NGC 5247) while only a marginal correlation can be seen in spirals with weaker patterns.

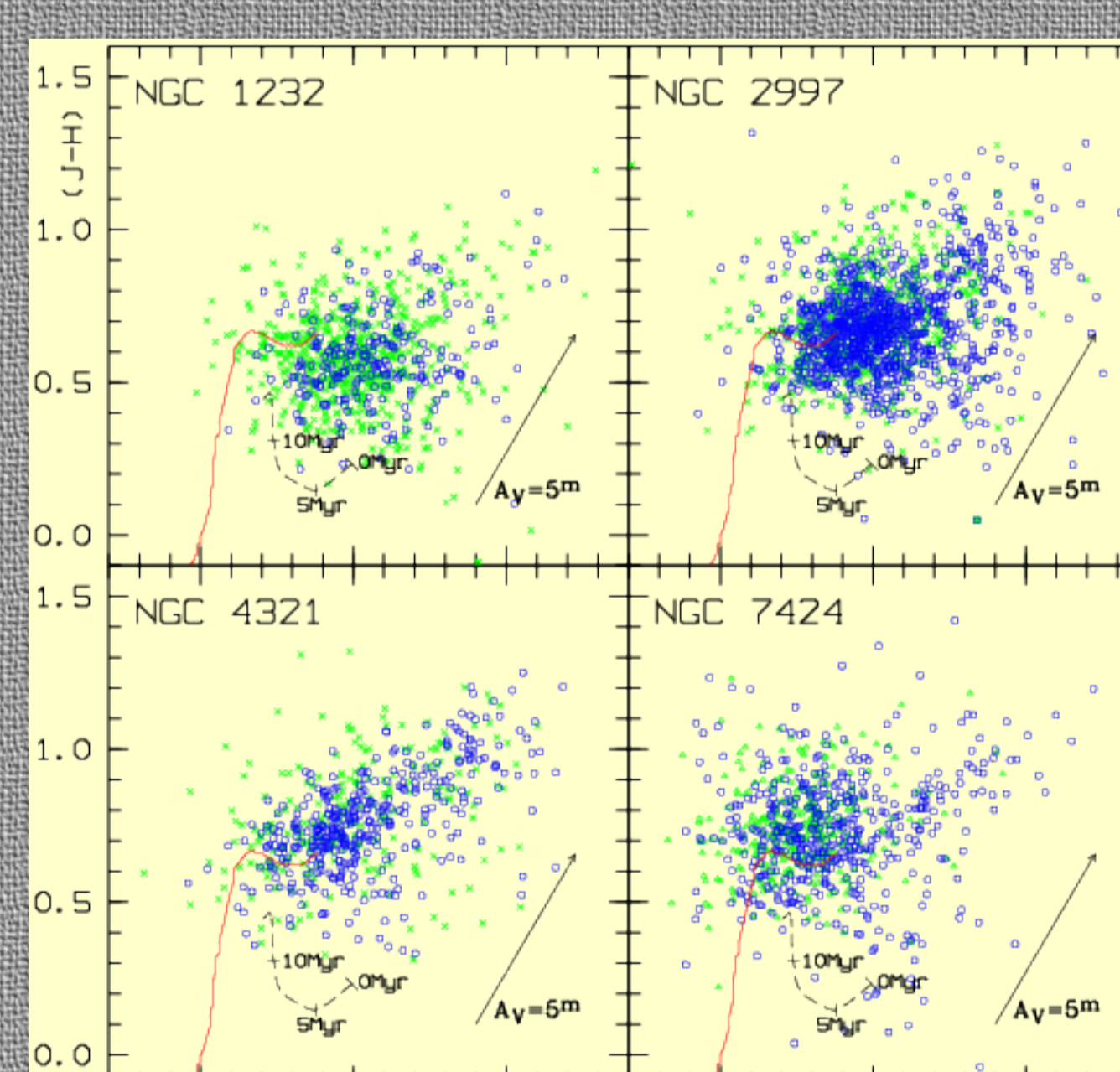


Fig.4: (H-K)-(J-H) diagrams for non-stellar objects found in the disks of 4 galaxies where blue point indicate more diffuse sources. The red line indicates the stellar main sequence while the dashed line shows a typical evolutionary track for a cluster using a SB99 model with continuous star formation. A typical reddening vector is shown.

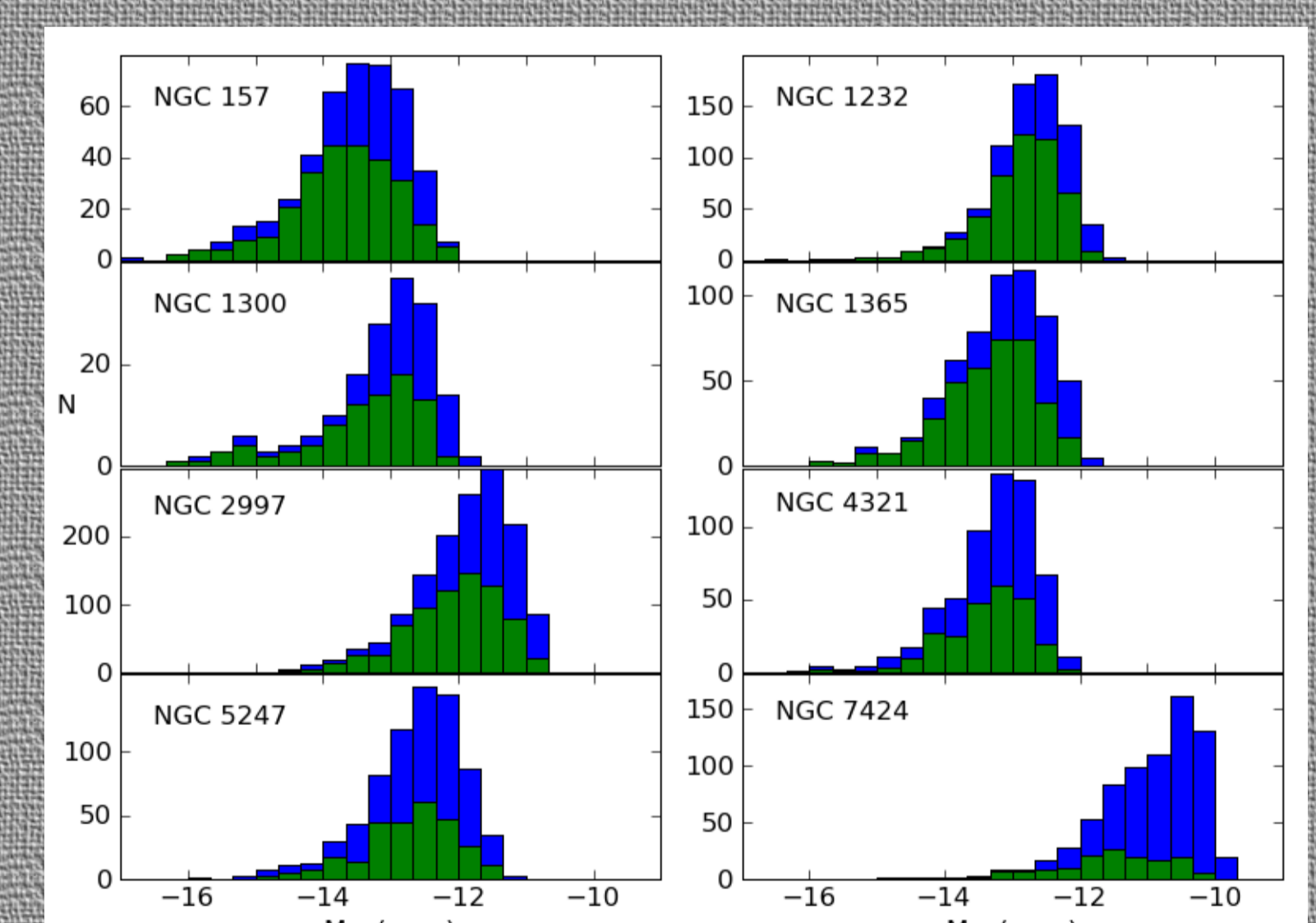


Fig.5: Histograms of absolute  $M_K$  magnitude for non-stellar sources in the galactic disks of the 8 spirals. The blue histogram represents all non-stellar sources with errors  $< 0.1^m$  while the green is for young sources with  $0.1^m < Q$ .

## Colour and Magnitude Distributions

The colour distributions of non-stellar objects in 4 representative galaxies are displayed in Fig.4 as (H-K)-(J-H) diagrams using only data with errors  $< 0.1^m$ . A typical SB99 evolutionary track for a stellar cluster with continuous star formation is shown by a dashed line. The standard reddening vector for  $A_V = 5^m$  is indicated. Diffuse sources (i.e.  $cs < 0.3$ ) are shown in blue while more compact ones in green. The diagrams show that the extended sources are consistent with them being stellar clusters reddened by several magnitudes of visual extinction. All galaxies have similar colour-colour distributions but they vary in total number, fraction of old to young objects, and ratio of diffuse to compact sources.

The histograms of absolute K magnitudes,  $M_K$ , of non-stellar sources are presented in Fig. 5 where blue bars show the total sample with errors  $< 0.1^m$  while the green ones only include young complexes. The distributions show a bright tail, reaching almost  $M_K = -16^m$ , largely composed by young sources and a sharp decline at the faint end. The exact values depending on the adopted distance scale e.g. using 3K CMB velocity corrections NGC 2997 would be at 19.2 Mpc instead of the adopted 11.9 Mpc.

A special case in the sample is NGC 7424 which is of type Sc(s)II.3 and has a fainter total visual magnitude, less FIR flux, and a much weaker spiral pattern than the other galaxies. Its clusters are fainter and have a very small young fraction although the total number is comparable. This may be caused by its weak spiral perturbation and a low amount of dust.